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AIRPLANE SPRAYING FOR FOREST PEST CONTROL

By J. S. Yuill and C. B. Eaton, Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine, and D. A. Isler, Division of Farm Machinery, Bureau of Plant Industry, Soils, and Agricultural Engineering

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In the short period since the end of World War II airplane spraying has been developed into an accepted means of combating forest-insect pests. This rapid expansion has been accompanied by a series of growing pains. Equipment, spray formulas, and operational procedures have not been standardized, nor have the limitations of aerial application been fully evaluated. Consequently, there is at times considerable uncertainty as to where and how this method can be employed effectively.

The purpose of this article is to summarize current information on the subject. However, it must be emphasized that--

(1) All statements in this article apply specifically to forest spraying and may not be applicable to operations for controlling crop pests or other insects.
(2) These recommendations are not final. Revisions will be necessary as methods are improved.
(3) No one set of recommendations can be made to apply to all situations. Details must be altered to meet local conditions.

Advantages and Limitations of Aerial Spraying

Compared to ground equipment, the principal advantages of aerial spraying for forest-pest control are speed, ability to reach otherwise inaccessible areas, and economy. By means of aircraft large forested areas can be treated, and they can be covered rapidly to permit critical timing of applications. The cost of treatment, including materials, ranges from about 70 cents to 3 dollars or more per acre, depending on the size of the area, its location, and the dosage applied. Similar coverage with ground equipment entails far greater costs.

The principal disadvantage of the method at the present time is that it does not give so uniform or so thorough coverage, and therefore is not so effective as ground equipment in the control of certain insects. Furthermore, adverse weather conditions may cause serious interruptions in spraying operations at times, and its use may be limited by extremely rough terrain.

In general, although aerial spraying has been most effective in controlling forest insects that actively move about in the tree crowns, such as the gypsy moth, the tussock moth, sawflies, and spittlebugs, it has also controlled certain less active ones. For example, outbreaks of the spruce budworm in Oregon have been controlled successfully, and experimental treatments applied to lighter infestations in the Northeast have given promising results. For the most part bark beetles and terminal feeders have not been effectively controlled by this method, although in recent experiments helicopter spraying appears to have given good protection from attacks of the white pine weevil.

Aerial spraying operations have been conducted successfully over terrain ranging from flat pine lands in Arkansas to steep, rough mountain areas in western New York, northern Idaho, and Oregon. However, it has been found dangerous to spray in blind canyons, on steep slopes where down drafts prevail, and in other situations where emergency maneuvers are restricted. This has been particularly true of operations in the mountain areas of the West. In those areas unfavorable air currents are more prevalent than elsewhere, and the performance of aircraft is considerably reduced by the increased altitude.

There are also certain legal limitations and requirements which should be investigated when an aerial spraying operation is being planned. For instance, the Civil Aeronautics Administration requires (1) that all aircraft, and the spray equipment installed in them, be approved for airworthiness, (2) that pilots operating for hire have a commercial pilot's license, and (3) that waivers for low flight be obtained in advance. Full details of these requirements can be obtained from the nearest CAA regional office. In addition, some States have restrictions on the kind and quantity of insecticide that can be applied from aircraft, and require that operators be licensed for this type of work.

Types of Aircraft

No existing model of aircraft is ideal for forest spraying. However, several have given reasonably satisfactory performance. Most of the work at present is being done with biplane trainers, Stearman and N3N. These planes are sturdy and dependable. They operate at about 80 miles per hour and carry approximately 70 to 100 gallons of spray when equipped with standard engines of 220 or 235 horsepower. Performance is satisfactory up to an altitude of about 5,000 feet. With engines developing 300 or 450 horsepower the spray load and performance are greater. Some of the larger single-engine, high-wing monoplanes, such as the Stinson SM7A, when provided with adequate power, have been quite satisfactory. Small two-passanger monoplanes have not been used extensively for this purpose, because of their limited spray load and range. Multi-engine transports and converted bombers (Ford Trimotor, DC-3, B-18) have given good performance for large-scale operations. They carry loads of 400 to 1,000 gallons, or more, and have been particularly suitable in treating extensive areas at considerable distances from airfields. They are not employed, however, where the terrain is extremely rough, and in all operations they are flown at a greater height above the trees than are the more maneuverable light planes.

Helicopters have been used to a limited extent in forest spraying. Best results have been obtained in treating plantations and other small areas where the high maneuverability and the ability to land and take off from adjacent open ground have been advantageous. The chief limitations for this type of aircraft are high initial and operating costs and small spray loads.

Spray Equipment

At the present time various types of spray equipment are used by commercial operators. However, not all types are satisfactory for forest spraying. Satisfactory performance of any given type for crop-pest or mosquito control, moreover, does not necessarily guarantee its

suitability for forest spraying. In general, equipment should be so constructed as to provide the following:

(1) Dispersal of the spray liquid from the plane at a uniform rate.
(2) Proper discharge rate to give the required dosage (gallons per acre).
(3) Adequate agitation in the spray tank (necessary when suspensions or unstable emulsions are used).
(4) Correct atomization of the spray liquid for its maximum lateral distribution (swath width) beneath the plane.
(5) Proper location of nozzles or other outlets to avoid excessively heavy deposits in the center of the spray swath.
(6) Metal parts that are resistant to corrosion.
(7) Hose and flexible connections that are resistant to naphthenic solvents commonly used in DDT sprays. (Standard aircraft gasoline- and oil-resistant hose has been satisfactory.)

A relatively simple boom-type sprayer has proved quite satisfactory on biplanes in forest spraying. A diagram of this apparatus is shown in figure 1.[1/] With modifications it has also given good performance on other single- and multi-engine planes.

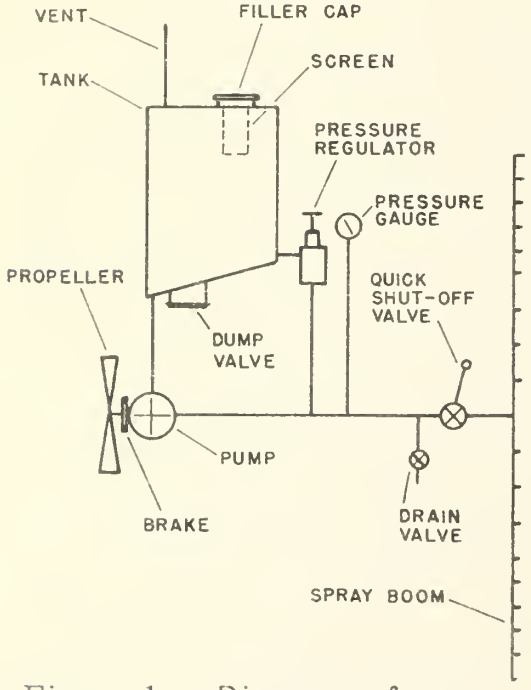

Figure 1.--Diagram of spray apparatus.

A discussion of the selection or construction of the component parts of an aerial spray system, its installation, and calibration follows.

Tank

The spray tank is usually mounted in the front cockpit in biplanes, behind the pilot's seat in light cabin-type planes, and in the cargo space of larger ships. Its capacity depends on the space available and the load permitted by CAA regulations for each plane. If space permits, it should have a sloping bottom to provide positive drainage of the liquid and to facilitate cleaning when changing from one type of spray mixture to another. A removable screen

1/ For detailed drawings see Aerial-Spray Equipment for a Stearman N2S Airplane, by D. A. Isler, U.S. Bur. Plant Indus., Soils, and Agr. Engin., Inform. Ser. No. 87, 13 pp. 1948.

strainer, not less than 40 mesh, should be fitted into the tank filler neck to remove any sediment in the spray liquid. There should be a dump valve to permit the pilot to reduce the spray load quickly in case of a partial power failure or other emergency.

The tank must also be provided with an air vent to prevent the development of negative pressure. Such a vent should be attached to the top of the tank or the filler neck. The vent opening should be outside the cockpit or cabin so that fumes or spray liquid cannot reach the pilot. The size of the vent required will depend on the discharge rate of the spray apparatus. On planes equipped with dump valves it must be large enough to permit free discharge of the anticipated flow rate from the valve. For planes discharging up to 25 g.p.m. (gallons per minute) the vent should be at least 3/4 inch i.d. (inside diameter), and for 50 g.p.m. the vent should be at least 1 inch i.d. For higher discharge rates the internal area of the vent should be increased in direct proportion to the increase in discharge rate.

Pump

Discharge of the spray at a uniform rate is essential. In general systems in which pressure is maintained by means of a pump have given the most satisfactory results. Gravity-flow systems do not discharge uniformly unless some means of compensating for the decreasing static head of liquid as the tank empties is provided.

Positive-displacement (gear and other rotary) and centrifugal pumps are used on spray planes. The gear and other rotary pumps are suitable for spraying solutions or emulsions. However, they are subject to excessive wear if used for spraying suspensions or any liquid containing abrasive material, or if allowed to rotate after the tank is empty. With any pump of this type there must be a bypass line or some other means of relieving the excessive pressure that builds up in the liquid lines when the control valve is closed. Centrifugal pumps, on the other hand, are satisfactory for all three types of spray--solutions, emulsions, and suspensions--and they develop adequate but not excessive pressure.

The size of pump to be selected depends on the capacity required of it in relation to the swath width, plane speed, and application rate. The capacity should be about 20 percent greater than the maximum flow rate required, to insure adequate agitation and to provide a factor of safety to compensate for losses due to friction and decreased efficiency due to wear of the pump. For biplane trainers the 1-inch gear and centrifugal pumps are adequate. For estimating pump capacities for other planes see the section on calibration, p. 8.

On light planes to insure positive flow of liquid from the tank to the pump, particularly when a centrifugal pump is used, the pump is generally mounted on the landing-gear members, or in some other convenient location below the level of the bottom of the tank. When so

mounted it is driven by a small wood propeller or a truck radiator fan fitted on an extension of the pump shaft. If a metal fan is used the hub or spider should be reinforced with aircraft steel and high-shear rivets to prevent failure due to fatigue or shearing of rivets. If the pump is not made with an outboard radial and thrust bearing, one must be provided to prevent excessive wear of the other pump parts. A small drum and brake band, with a control to the cockpit, may be installed so that the pump can be stopped when the plane is not spraying. In some of the light planes the pump is driven by power take-off from the airplane engine, or by either an electric or hydraulic motor. In larger planes one or more pumps may be used. They are ordinarily mounted in the cargo space and are driven either by separate gasoline engines or by an electric or hydraulic motor.

Whatever type of pump installation is used, it is essential that all fittings, valves, and liquid lines be large enough to permit unrestricted flow of the spray from the tank through the pump to the nozzles. Otherwise the delivery of spray from all outlets will not be uniform and the proper atomization will not be obtained. In the biplane trainers 1 1/4-inch lines are preferable; no lines should be less than 1 inch in diameter. In larger planes, where higher flow rates are required, the size of lines should be increased accordingly.

Pressure Regulator, Drain, and Shut-off Valves

Pressure regulators are not found on all spray planes. Their use is recommended, however, for the following reasons: (1) They prevent excessive pressure in the liquid lines when positive displacement pumps are used, (2) they insure a uniform flow rate at all times by holding a constant pressure, (3) within limits, the flow can be changed as needed, without altering the degree of atomization, by increasing or decreasing the number of nozzles and resetting the regulator to the original pressure, and (4) the liquid returned to the tank through the bypass line provides some agitation to the liquid in the tank. For effective agitation the bypass line should discharge near the bottom of the tank rather than at the top. This arrangement will also reduce foaming when emulsions or suspensions are being applied. The pressure regulators used on N3N and Stearman planes usually are of the standard hydraulic-relief valve type. They can be purchased pre-set for various pressures and can be adjusted through a range of about 20 percent above or below the normal pressure. Some models are rather heavy, but the weight can be reduced by turning down the valve body in a lathe. Diaphragm-type pressure regulators and flow-regulating gate valves also may be used to adjust the spray pressure, provided a relief valve is installed to prevent an excessive pressure on the inlet side of the regulator. Regardless of the type of regulator, it should be installed near the pilot so that he can adjust the

pressure during flight. A pressure gage should be mounted in the cockpit so that the pilot can see that the proper pressure is being maintained.

Drain valves are desirable but not essential. They are particularly convenient when it is necessary to flush out the tank and pump or to determine the flow rate.

Shut-off valves usually are of the cam-action, quick-opening gate types. Such valves have straight-through, full-area openings. The opening should be of the same size as the pump discharge line in order to permit unrestricted liquid flow. Sliding gate valves and three-way valves are also used in some installations, and solenoid-operated valves on some planes that have suitable electrical systems. Globe-type valves are not recommended.

Atomizing Devices

The types of atomizing devices used on spray planes are too numerous to describe here. For general forest spraying nozzles in combination with the pressure system described in the preceding section have been the most satisfactory. They have the following advantages over many other devices:

(1) The flow rate can be changed without affecting the atomization by merely adding or removing nozzles. (In adding nozzles the total output must not exceed the capacity of the pump.)
(2) For each condition of flow rate and atomization the location of the outlets can be adjusted to obtain the maximum swath and to reduce excessive deposit within the swath.
(3) They are comparatively cheap.

Nozzles delivering a hollow-cone or flat spray, and made without cores, vanes, or disks, produce a narrow range of atomization (fewer excessively large or exceedingly small drops) for a given capacity and have less tendency to clog. Nozzles of this type with 1/8-inch-diameter orifice and a rated output for water of 0.8 g.p.m. per nozzle at 25 p.s.i. (pounds per square inch) have given good performance on biplanes. The orifice can be directed to the rear to produce a moderately coarse spray or forward to obtain a medium spray.

For simplicity of installation the nozzles are usually mounted on a tubular boom, hung on brackets beneath the wing (beneath the lower wing on biplanes); but the boom may be installed inside the wing and the nozzles attached to pipe nipples extending beneath the wing surface. Biplanes equipped with a cluster of nozzles beneath and inboard from the wing tips and a cluster at the tail section have been used for some specialized applications. These internal boom installations reduce drag considerably, but are not so readily adaptable to the varying needs of most commercial operators as are the external-boom installations.

Regardless of whether an internal or external boom is used, slightly over half, but not over two-thirds, of the nozzles should be evenly spaced in the outer half of the wing span to provide for maximum lateral distribution of the spray.

There are several devices for preventing the dribbling of spray liquid from the nozzles after the spray valve has been shut off. A shut-off valve at each nozzle or group of nozzles is probably the most effective, but a check valve at each nozzle is the most common. Special selector valves which vent the boom back to the tank or permit application of negative pressure to the boom are also used.

Calibration

The importance of proper performance in spray equipment cannot be overemphasized. Unfortunately the methods required for precise evaluations of equipment are too involved for use in the field. However, the tests described below will give a rough estimate of performance and and should bring out any serious inadequacies.

The flow rate, or output, can be determined as follows: (1) Put a measured amount of spray liquid in the tank, (2) have the pilot turn the spray on for a timed interval (30 or 60 seconds) while in straight and level flight at the air speed to be used in the spraying operation, (3) when the plane lands, drain and measure the liquid remaining in the tank, and (4) compute the flow rate in gallons per minute. An alternate method is to (1) fill the tank to a definite level such as a specific point in the filler neck, (2) fly the plane as described above, (3) after landing, spot the plane in exactly the same location used when filling the tank and measure the amount required to refill to exactly the same level, and (4) compute the flow rate as above. Two or three replicate flights should be made, and the results for any one spray mixture should not vary by more than 3 percent. Fuel oil alone can be used for determining the flow rates of DDT-fuel oil solutions. For emulsions and suspensions the mixed sprays should be used. The flow rate required can be computed by the formula

$$F = \frac{S\,W\,D}{495}$$

when F = flow rate (output) in gallon per minute
S = speed of the plane in miles per hour
W = width of effective swath (not total swath) in feet
D = dosage to be applied in gallons of liquid spray per acre

The swath width of planes equipped with a full-wing-span boom can be estimated roughly by multiplying the wing span by 4. However, this is only an approximation. It applies only to planes in which spray is released over the full wing span, and from a height above the trees greater than the wing span.

More reliable estimates can be obtained from actual test flights over open ground. These tests should be made just after dawn in winds of not over 4 miles per hour. Glass plates 2 to 4 inches square are used to collect the spray deposits. A day or so before the tests they are cleaned and then coated with a thin film of zinc stearate to prevent the spray drops from spreading into a film on striking the surface. Zinc stearate can be obtained from any drugstore or chemical supply firm. A small amount of this material is placed on each plate (about the size of a match head for a plate 2 inches square). It is then melted by warming over a hot plate, and spread evenly with the finger. Paper or uncoated glass cannot be used, since the drops spread excessively and unevenly on these materials. The plates are placed on wood blocks or other supports to keep them above grass or other vegetation, at 10-foot intervals on a line 400 to 1,000 feet long, and at right angles to the wind direction. With fuel oil as the spray (water or emulsions evaporate too rapidly) the plane is flown directly into the wind and over the center of the line of plates. The flight altitude should be the same as the height above the trees and the air speed of the plane should be the same as that at which control applications will be made.

In tests of this kind the spray should be turned on when the plane is about 500 feet downwind from the test line and left on as the plane continues in straight and level flight for at least 1,000 feet upwind from the test line. The plates are left in place for about 5 minutes after the plane passes to allow the spray cloud to settle to the ground. Then a visual estimate of the quantity and size of spray drops is made by comparing them with photographs of known sizes and quantities of drops. (See Appendix, p. 17.) The estimates should be made within 20 minutes after the spray flight; otherwise there may be considerable evaporation of the deposited drops. Test flights should be repeated once or twice to avoid erroneous estimates that may result from drifting of the spray during the time the cloud is settling.

When the plates are examined, it will be found that the quantity of spray deposited decreases from the center to the margins of the swath. For a Stearman plane equipped with a boom-type sprayer adjusted for a calculated discharge rate of 1 gallon per acre, the rate of deposit on the plates should not exceed 1 gallon and not be less than 1/2 gallon per acre at the center of the swath. At a distance of 60 feet from the center, the rate of deposit should not be less than 1/4 gallon per acre, and at 100 feet not less than 1/10 gallon. Where larger planes with similar equipment are used, deposits in the center of the swath should be approximately the same as for a Stearman, but the total swath should be greater depending on the size of the plane. For control of most defoliators the effective swath may be considered as the distance over which the rate of the deposit is not less than 1/4 gallon per acre. The effective swath for a Stearman with boom sprayer should be about 2 chains (132 feet) wide.

It has been found that the heaviest deposits (near the center of the swath) usually are made up of drops having a wide range in size. Moving outward from the center the range becomes narrower until at the margins there is only a sparse scattering of very small drops. Since the center portion contains the full range of drops from the smallest to the largest, only that portion need be examined in making estimates of drop size. The largest drops should be at least 300 but not greater than 600 microns in diameter (1 micron = 0.001 mm. or about 0.0004 inch).

Spray Mixtures

Of the many types of insecticidal spray materials available on the market today, only oil solutions of technical DDT have been used commonly for forest spraying by airplanes. DDT emulsions have been used, but only to a limited extent. Suspensions of DDT, either in the wettable-powder form or as colloidal dispersions, likewise have not been commonly used. The value of some of the newer insecticides for this type of spraying has not yet been adequately determined. Research is being continued in an effort to find the most effective and economical chemical and formulation for these purposes. The present recommendations are offered merely as being the most satisfactory ones yet tested.

In the preparation of oil solutions of DDT the usual procedure is first to dissolve the DDT in a naphthenic solvent and then dilute this mixture to the required volume with No. 2 fuel oil. In warm weather 1 quart of the solvent per pound of DDT should be adequate, but if the spray is to be exposed to subfreezing temperatures the amount of solvent should be increased to 1 1/4 or 1 1/2 quarts per pound.

Around reservoirs or other places where this solution might impart an objectionable taste to domestic water supplies, xylene and kerosene can be substituted for the naphthenic solvent and the fuel oil. However, except in just such special cases, xylene and others of the lighter solvents are not recommended. They do not retain the DDT in solution at low temperatures, and tend to evaporate rapidly in the air; furthermore, low flash-point products present a possible fire hazard. In large-scale operations these DDT solutions may be purchased, ready for use, according to specifications.[2/]

In small operations it may be more economical to purchase commercial brands of solvent concentrates, or even to prepare the spray on the job. Commercial concentrates should contain about 30 percent of DDT and should be made with a suitable solvent. These concentrates are diluted with a fuel oil prior to application. Where the spray is to be prepared

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2/ A general guide for use in preparing specifications is presented in the Appendix.

on the job, drum lots can be mixed with the apparatus shown in figure 2. It is prepared as follows: Warm the solvent to about 70° F. by placing the container in the sun, or by means of a hot-water coil, and then pour it into the drum. CAUTION: Solvents are inflammable. Use proper precautions. Place the DDT in the wire basket, add the solvent, and circulate it until the DDT is dissolved. Add fuel oil until the required volume of finished spray is obtained and then circulate the liquid again for thorough mixing. Where it is desirable to mix larger batches, an orchard-type power sprayer with a steel tank can be used in the same manner. Running the agitators during mixing will speed the operation.

Oil solutions are usually applied at the rate of 1 pound of DDT in 1 gallon of solution per acre. Against very active defoliators in the outer and upper portions of the tree crown, however, 1/2 pound of DDT in 1 gallon has given good results. Although there has been some spot burning on broadleaved trees, and occasionally some dropping of old needles on pine, fir, and spruce at these dosages, in no case has there been serious injury.

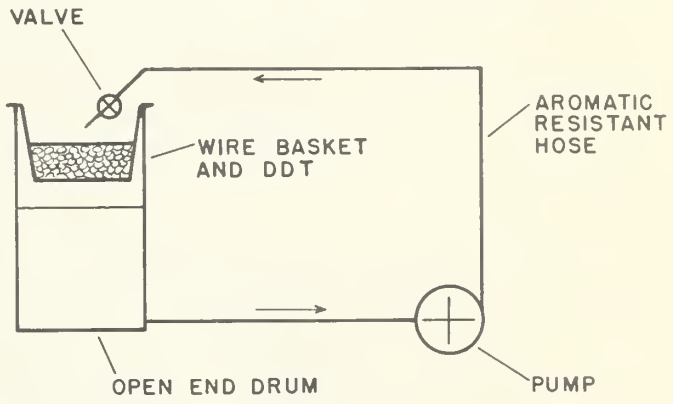

Figure 2.--Diagram of apparatus for mixing small quantities of spray.

Spraying Operations

When an extensive area of several thousand acres is to be treated, the application of spray usually is contracted to the commercial operator offering the lowest bid for the work. For a smaller area it may be more satisfactory to employ a reliable local operator without the formality of a contract. In either case, however, the success of the operation depends largely on careful planning. In forest spraying there are innumerable details that vary with different conditions, all of which must be anticipated for efficient execution of the program. A few of the more important ones are described below; others will become apparent as the work is planned.

Selecting a Base of Operations

In selecting an airfield or landing strip for forest spraying, one must consider the distance to the area to be treated, the length and condition of runways, and the servicing facilities.

The maximum practical ferry distance between the landing strip and the area to be treated will depend on the operating range of the aircraft. However, regardless of the type of plane the shorter the distance the better.

Much valuable time can be lost and the cost of the operation increased by long ferry trips. In some cases it may even prove practical to construct temporary landing strips within or near such areas to reduce ferry time.

The length of runways required will depend on the type of plane to be used. For the light biplanes the minimum length is approximately 800 feet. In the higher altitudes, during hot, humid weather or on a soft surface, however, longer runways are necessary. Runway surfaces should be smooth enough to permit driving an automobile over them at 40 miles per hour.

Facilities for rapidly servicing the planes should be provided at the airfield. If not already available, aviation gasoline of the proper octane rating should be brought in. It may be dispensed from drums or a tank mounted on a truck. A suitable hand-operated or small engine-driven pump will greatly simplify loading the gasoline in the airplane. When a gasoline engine-driven pump is used, however, care must be taken never to permit the exhaust to be directed toward open drums. A fire extinguisher should be handy at all times. If gasoline drums or tanks contain sediment or water, the gasoline can be strained through a chamois-lined funnel while it is being pumped into the plane. The spray liquid may also be carried in drums or tanks on a truck and pumped directly into the plane. All pump parts and hose should be oil-resistant, because DDT solvents are destructive to natural rubber.

Subdividing and Marking of Treatment Areas

In large forested areas the portion to be sprayed is usually divided into units that can be treated in 1 to 3 days. If the area to be treated is broken by uninfested forest types or cultivated areas, it is divided into still smaller units. Sometimes these units can be laid out in rectangular shape. However, it is generally more practical to use ridges, roads, and other features of the terrain as the unit boundaries. Large-scale topographic maps, aerial photos, and aerial mosaics are particularly helpful in this connection. If possible the pilot or chief pilot in charge of flying operations should be consulted when the treating units are marked out on the maps.

On many spraying operations markers are used to aid the pilot in locating the various treating units and in maintaining an accurate flight pattern. These markers may consist of white or orange flags, small wind socks, or light-colored feed sacks stuffed with brush; and they may be placed in the tops of trees or raised on sectional magnesium poles. In stands of relatively short timber the usual practice has been to climb the trees and rope or wire the markers in place. A recent interesting innovation in the West, where the height of the trees made climbing impractical, was the employment of a line-throwing shoulder gun to pass a light cord over the top of a tall tree to be used as a marker. A flag or paint bomb was then hauled up on the cord to mark the location.

On large units the markers are spaced at predetermined intervals along two opposite sides of a unit, and the pilot is instructed to apply the required number of swaths between them. Where roads or trails occur along one or two sides of a unit, a small captive meteorological balloon is used to mark each spray flight line. Here, the balloon, inflated with helium or hydrogen and attached to a light cord, is allowed to rise about 40 feet above the canopy. The pilot flies directly over the balloon, which is then moved one swath width along the boundary and another spray run is made over it. This procedure minimizes application errors, but can be employed only where continuous openings in the canopy allow the ground crew to move the balloon quickly along the boundary. For spraying plantations colored cloth panels on bamboo poles can be substituted for the balloons. Smoke flares have also been tried, but they are not recommended where they might create fire hazards.

Communications

Whenever possible some means of communication between the airfield, the treating area, and the pilot should be provided during the spraying. This should be done because, even with the most careful planning, unexpected situations that require changes in procedures always arise during actual spray operations. A radio telephone is probably the most satisfactory solution of this problem. Although most spray planes do not have radio equipment, with a proper ground set at the treating area and another at the airfield, information or instructions can be relayed as necessary. When these ground sets are not available, local telephone service may be such that a field telephone can be installed in or near the treating area and at the airfield.

If neither radio or telephone is available, a system of signals may be used. One such signal system that has been satisfactory is to place a truck in a open spot visible from the air, and adjacent to or within the area being treated. When a white cloth panel is placed on the truck cab, the pilot will apply the spray as previously planned. When an orange panel is displayed, he will return to the airfield for instructions. If neither panel is shown, he will circle the area until one or the other is displayed. This system can be varied at will, but to avoid confusion the number of signals should be kept at a minimum.

On certain large spray operations in the West it has not been possible to have ground personnel in each unit or block being treated. Under such conditions there has been little need for ground-to-air communication. However, even then telephone or radio communications between headquarters and outlying landing strips have been helpful.

Pattern and Altitude of Flight

The flight pattern to employ in applying the spray is governed primarily by the shape and topography of the unit being treated. Where the unit is approximately rectangular and the topography is flat, the grid type of

pattern usually is the most satisfactory. This pattern requires the pilot to fly in parallel lines back and forth across the unit from one side to the other, the distance between the flight lines being the same as the effective swath width of the spray plane.

Where the spray unit is irregular in shape and the terrain is steep, flights should be made along the contours or down slope. It is not safe to fly up slope, especially with a heavily loaded plane at high altitudes. It is very difficult to obtain a uniform coverage of forests in such areas. Chances for error in spacing the flight lines are greater and, since the direction of the lines changes with the topography, it is possible that the pilot will leave some spots untreated while giving others a double treatment. The chance of this happening may be so strong in some cases that it will be advisable to increase the rate of application by reducing the distance between flight lines.

With light planes it is desirable to apply the spray from an altitude of approximately 50 feet above the treetops in order to obtain the maximum swath width without excessive loss of spray by drift. For safety, however, the altitude must be increased when there are obstructions such as snags, where the terrain is rough, or when larger planes are used. With fixed-wing aircraft spraying should never be done at less than 50 feet above the treetops. Generally the altitude and other flight procedures should be determined by a pilot, or chief pilot, who is well experienced in forest spraying, in consultation with the supervisor of the control operation. A qualified pilot will know the performance characteristics of his plane and the limitations imposed by topography, elevation, and associated air conditions.

Weather Conditions that Limit Spraying

One of the greatest limitations in airplane spraying is the weather--specifically, air movement and rain. Wind may cause excessive drift of the falling spray, and convection currents (thermals) may prevent it from descending into the trees. Forest spraying, therefore, should not be attempted when the wind velocity above the trees exceeds 8 miles per hour, or when there is enough convection to make the air bumpy. Air movement is usually at the minimum about dawn. On good days spraying can be started as soon as there is sufficient light and continued for 3 to 4 hours. In some localities a short period in the evening may also be favorable.

The presence of water on foliage may reduce the effectiveness of spraying. A moderate amount of moisture is not serious, but when it drips from the leaves an appreciable amount of the falling spray may be carried off. Similarly, when a heavy rain falls before the spray deposit has dried on the foliage, enough insecticide may be lost to necessitate respraying. Spray deposits usually dry in 1/2 to 4 hours, depending on the temperature. Deposits of DDT-oil sprays, once they have thoroughly dried on the foliage, will remain effective for 1 to 2 weeks under average conditions.

Observations during Spraying

While the spray is being applied, one or more observers should be stationed at vantage points in or near each unit being treated. It should be their job to see (1) that weather conditions within the area are satisfactory for spraying and (2) that the pilots are maintaining the proper flight pattern and altitude. When they find that the wind velocity (preferably measured by field anemometers) exceeds the maximum allowable for adequate control, or that the spray is not descending into the trees properly, they should either inform the man in charge of the operation or signal the pilot to stop spraying.

If possible additional observers should be present in each unit to check on the spray coverage. They should place clean glass plates (each about 4 by 4 inches), preferably in openings, at 50 to 300 foot intervals across the unit, or in as many parts of the unit as possible. They should examine the plates after the morning spraying. If the application has been uniform, they will find that all plates will carry at least a light deposit of small drops. The number of plates to use will vary with the density of the forest canopy. Where solvent-fuel oil solutions of DDT are applied, a very thin oily film or sheen will be visible on the foliage. This too, may be used as an index of coverage, for if most of the leaves on the lower branches and on the understory plants have a visible film or spots of the spray, it is reasonably certain that the upper tree crowns have been adequately treated. The observers should locate all skips or misses in the deposit and spot them on a map for retreatment.

Evaluating Results

The success of any spray job is measured by how well it controls the pest being treated. Determining the degree of control is therefore an essential part of the job. Even under what appear to be excellent conditions of weather and application, there is always the possibility of something going wrong so that the final results will not be satisfactory. Therefore, a preliminary estimate should be made soon after the application in order that any parts of the area in which control is inadequate can be re-treated immediately.

Usually the effect of DDT spray on insects will be apparent in 24 to 48 hours, although in cool weather it may be delayed 3 to 4 days. At the proper time trees should be examined at random points throughout the area to estimate the proportion of the pests killed. It is sometimes helpful to place cloth trays beneath trees at various locations, to catch the poisoned insects that drop or spin down on threads. If the spraying has been successful, normal survivors will be hard to find and at least 95 percent of the pests will have been eliminated.

The preliminary estimates alone, particularly in the case of defoliating insects, will often show without question that adequate control has been obtained; in which case no further inspection will be needed. If doubt exists, a final survey may be necessary. The extent of the survey and the methods to be employed will be governed by the particular insect and the forest conditions. The details should be worked out with the help of an entomologist or forester who is acquainted with the insect problem in question.

PRECAUTIONS IN THE USE OF DDT

DDT is highly poisonous to many insects, including the beneficial ones. It is also poisonous to other forms of animal life and to man. Common-sense precautions should be observed in handling and applying DDT sprays. When planning a large-scale operation, consult the Federal Fish and Wildlife Service, Public Health Service, Department of Agriculture, or your State agricultural experiment station. Some of the more important precautions are listed below.

(1) When handling spray avoid spilling it on the skin. Don't wear spray-soaked clothing.
(2) Bathe and change clothing after each day's work.
(3) Don't leave spray or DDT where unauthorized persons or domestic animals can have access to them.
(4) Where cultivated fields, orchards, or pastures are adjacent to infested forest, the pilot should make proper allowance for wind to avoid spray drift onto agricultural land.
(5) Notify beekeepers in advance when sprays are to be applied in areas where their bees may be working, so the hives may be closed during application. Don't spray near hives.
(6) Whenever possible avoid spraying lakes and streams. Application rates above 1 pound of DDT per acre kill some fish.
(7) Don't overdose on the theory that if enough is good more is better. Application rates above 2 pounds of DDT per acre have been injurious to nestling birds; higher rates may be harmful to other wildlife.

Appendix

Specificiations for Spray Materials[3/]

These specifications and requirements for the purchase of spray materials are intended primarily as a general guide. For any specific spray operation some changes may be dictated by the quantities required, availability of materials, and transportation costs.

(1) DDT, technical grade.

Setting point, 192.2° F. minimum.
Organic chlorine, 48 to 51 percent by weight.
Ash content, 0.5 percent by weight, maximum.
Chloral hydrate, 0.025 percent by weight, maximum.
pH by extraction, 5.0 to 8.0.
Water-soluble material, 0.25 percent by weight, maximum.

Methods for determining these characteristics are given in Federal Specification O-D-370, May 13, 1949. The material should be a fine to medium granular powder with a white to cream color.

(2) Auxiliary solvent for DDT.

The auxiliary solvent shall consist principally of hydrocarbons and shall have the following physical characteristics:

Flash point (Cleveland open cup) not less than 160° F.
Distillation range:
  Initial boiling point not less than 360° F.
  Final boiling point not greater than 750° F.
Viscosity (Saybolt Universal) at 100° F., 30 to 55 seconds.
DDT solubility, at 32° F., not less than 30 percent by weight.
Relatively nontoxic to hardwood and coniferous foliage when the spray is applied at the rate of 1 to 2 gallons per acre. At present there is no standard laboratory test for this property.

(3) DDT solution--finished spray.

The DDT solution shall be composed of 1 pound of technical DDT in sufficient mixed solvent to make 1 gallon. The mixed solvent shall consist of No. 2 fuel oil and sufficient auxiliary hydrocarbon solvent, meeting requirements under (2) above, to prevent DDT crystallization at 32° F.

3/ Prepared by R. H. Nagel, Division of Forest Insect Investigations, and E. E. Fleck, Division of Insecticide Investigations.

On occasion low-priced hydrocarbon byproducts which are good solvents for DDT appear on the market. If such a product meets the specifications set up for auxiliary DDT solvents under (2), and prevents DDT crystallization at 32° F., it may be used without fuel oil dilution and may result in an appreciable saving in cost. The insecticide solution shall be clear, homogeneous, and free from particles of undissolved DDT or foreign matter. Containers shall be free of scale or other foreign matter.

(4) DDT solution--concentrate.

The DDT-solution concentrate shall contain at least 2 1/2 pounds of technical DDT per gallon of a concentrate made with a solvent meeting the requirements under (2).

(5) Contract purchase of spray.

For large-scale operations it is customary to purchase the spray, either in finished form or as a concentrate, by a bid contract. The following terms are usually included in the contract:

Specifications for the finished spray or the concentrate are stated.
Each bidder is required to furnish samples of the materials that he proposes to use.
Each bidder must submit data on his plant capacity and other information as evidence that he can insure delivery within the time limits specified.
The approximate amount of spray required is given, and the provisions are made that (a) within limits, additional quantities may be purchased at the same rate and (b) the purchaser may terminate the contract at any time should insect diseases or other circumstances make it necessary to reduce the area to be treated.

Estimating Deposit and Atomization

Sometime in the course of nearly every forest spraying operation, it is necessary to estimate the quantity of spray deposited and the size of the spray drops, either to evaluate the performance of spray equipment or to determine whether adequate coverage has been obtained. In either case actual measurement of deposit or atomization is impractical because of the time and special equipment required. On the other hand, a visual estimate of quantity of spray or drop size based only on the observer's judgment is almost valueless, because even among the most experienced people errors may be as great as 300 percent. Figure 3 shows samples

of the spray deposit as it appears to the unaided eye when collected on glass plates coated with zinc stearate as described on page 9. It will be seen (1) that these deposits vary in density and are composed of drops having a wide range in size, and (2) that the range in size of the drops and the quantity of spray deposit decrease with the distance outward from the flight line. Since it is impractical to prepare standards for illustrating all the combinations of drop size and deposit rates that occur, photographs of known quantities of deposits and of known drop sizes have been prepared (fig. 4).

These photographs show uniform drops as they appear to the unaided eye when deposited on glass plates coated with zinc stearate. The range of size given--50, 100, 200, and 500 microns in diameter--includes nearly all the drops that reach the ground from a spray plane. For each size there is also shown the density of drops required to give definite quantities of deposit normally encountered. Although these standards bear little resemblance to actual spray deposits, reasonably satisfactory estimates of the drop size and the quantity of spray can be made by using the standards as a basis for comparison with actual spray deposits collected in the field.

The drop size is determined by comparing the diameter of the two or three largest drops in the deposit sample with the drops in the standard photographs (fig. 4). For example, in the spray sample shown in figure 3, A, the largest drops are considerably larger than the 200-micron standards but not so large as those in the 500-micron standards; the estimate would therefore be about 400 microns.

The quantity of spray deposit in the sample can be estimated by the following procedure:

(1) Estimate the average size of the larger, more prominent drops. Those in figure 3, A, would be about 300 microns.
(2) Compare the density or number of these drops with the density of similar drops in the standards. The larger drops in figure 3, A, are somewhat more numerous than those in the 500-micron standard at 3/4 gallon per acre, but less numerous than the 200-micron drops at 3/4 gallon per acre. Since the size and the number of the larger drops in the sample lie between the two standards, the estimated quantity would be about 3/4 gallon per acre.
(3) Now in the same manner as for (1), estimate the average size of the smaller drops in the sample. In figure 3, A, this would be approximately 100 microns.
(4) Next estimate the density of the smaller drops, as in (2). In figure 3, A, they compare with the standard showing 100-micron drops at 1/4 gallon per acre.

(5) The estimate of the total deposit in the sample will then be the sum of the two previous estimates. In the example this is 3/4 plus 1/4 gallon per acre, a total of 1 gallon per acre.

At first a comparison of deposits containing a range in drop sizes may seem rather difficult, but with a little practice there should be few extreme errors. It should be remembered, however, that this method is suited only for rough and rapid determinations. Although the results are much more reliable than estimates made by even the most experienced observers without the aid of reference standards, this method will not give the accuracy of the more complicated laboratory methods.

Figure 3.--Example of aerial spray-deposit pattern: A, Center of swath, deposit rate of 1 gallon per acre, spray drops up to 400 microns; B, 50 feet from center, deposit rate of 0.5 gallon per acre, spray drops up to 300 microns; C, 100 feet from center, deposit rate of 0.2 gallon per acre, spray drops up to 150 microns; D,150 feet from center, deposit rate of 0.05 gallon per acre, spray drops up to 75 microns.

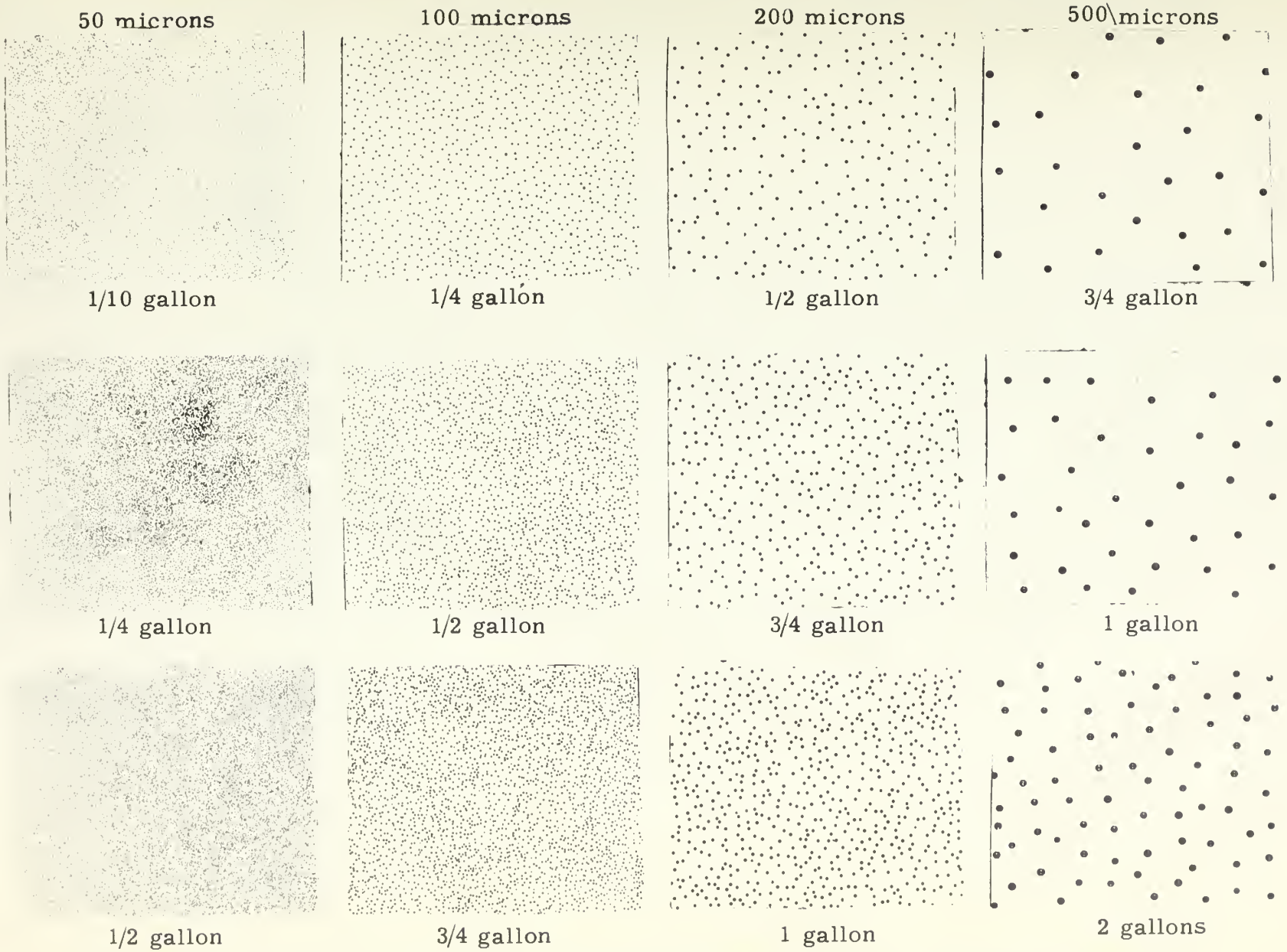

Figure 4. --Standards for estimating drop size and quantity of spray deposit per acre.

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